

Article

A systematic evaluation and benchmarking of summarization methods for biomedical literature: From Classical Models to LLMs

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Abstract

Draft: The exponential growth of scientific literature has created an urgent need for reliable tools that can distill research articles into concise and accurate summaries. In this study, we benchmarked 62 summarization models on 1,000 scientific abstracts with corresponding author-provided highlights as reference summaries. Models ranged from classical approaches – such as frequency-based and TextRank methods – to modern state-of-the-art language models were evaluated by using a comprehensive set of surface-level, Embedding-based and Performance metrics. By systematically comparing traditional and modern approaches, this work highlights their respective strengths and limitations, offering insights into effective strategies for accelerating knowledge discovery in the molecular sciences. A single paragraph of about 200 words maximum. For research articles, abstracts should give a pertinent overview of the work. We strongly encourage authors to use the following style of structured abstracts, but without headings: (1) Background: place the question addressed in a broad context and highlight the purpose of the study; (2) Methods: describe briefly the main methods or treatments applied; (3) Results: summarize the article's main findings; (4) Conclusions: indicate the main conclusions or interpretations. The abstract should be an objective representation of the article, it must not contain results which are not presented and substantiated in the main text and should not exaggerate the main conclusions.

Keywords: benchmarking; natural language processing; text summarization; large language models; biomedical literature

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1. Introduction

The exponential growth of scientific literature has created a demand for text summarization methods to support scientists in finding relevant information in an efficient way. Automatic text summarization (ATS) methods, ranging from statistical approaches to modern large language models (LLMs) have matured over time, enhancing their reliability in accurately summarizing relevant parts of complex research articles. ATS methods have been previously evaluated and described [1,2], but only few of them are tailored for scientific literature summarization [3,4].

The pre-neural era of text summarization was mainly characterized by extractive approaches, where in an unsupervised way, summaries were generated by using word

or concept frequencies to identify relevant sentences. The first word-frequency based approaches were discussed by Luhn [5], who presented a method based on the assumption that recurrent words in a text are likely more important. Later, Edmunson [6] introduced concepts such as cue words, title words, and sentence position to further enhance the automatic summarization process. The concept of Term Frequency–Inverse Document Frequency (TF-IDF) was later adopted [7] and applied to text summarization by representing sentences as term-weight vectors that down-weight common terms and on the other hand up-weight rare terms that might be of more relevance. Thus, word-frequency based approaches have been extensively used in scientific text summarization, being at the basis of more sophisticated strategies [8]. Lastly, graph-based methods were implemented, where sentences were represented as nodes and relations between sentences, calculated by using similarity measures (i.e cosine similarity of TF-IDF vectors), as edges. Two graph-based methods gained popularity in the biomedical domain: TextRank, that builds a graph by breaking down the documents into single sentences to then apply the PageRank algorithm to assign importance scores to sentences. The summary is then generated by using the top-ranked sentences [9,10]. LexRank, instead, uses eigenvector centrality to find the most influential ones in the graph [11].

With the advent of Sequence-to-Sequence (Seq2seq) frameworks, summaries were generated by paraphrasing and condensing text based on Encoder-Decoder architectures, originally implemented as Recurrent Neural Networks (RNNs), Long Short-Term Memory (LSTM) networks and Gated Recurrent Units (GRUs) [12,13]. The introduction of self-attention mechanisms replaced recurrent networks by processing sequences in parallel rather than sequentially, as a more effective method for capturing complex linguistic patterns and long context relationship [14]. This sets the basis for transformer architectures that quickly gained popularity in performing a wide range of Natural Language Processing (NLP) tasks such as text summarization. One of the earliest and most influential transformer-based models, BERT, (Bidirectional Encoder Representations from Transformers) [15] was widely adopted in domain specific tasks thanks to the possibility to be fine-tuned by adding a task-specific output layer. Inspired by the BERT architecture, different models capable of performing abstractive summarization emerged: BART, Bidirectional and Auto-Regressive Transformer, is a denoising autoencoder for pretraining sequence-to-sequence models [16] that can be trained or fine-tuned on scientific literature [17,18]. T5, Text-to-Text Transfer Transformer, was introduced as a unified text-to-text framework for a broad spectrum of NLP tasks due to its high flexibility with no need for architectural changes [19]. PEGASUS, Pre-training with Extracted Gap-sentences for Abstractive Summarization Sequence-to-sequence model, was specifically proposed for abstractive summarization tasks [20]. Notably, some PEGASUS versions tailored for scientific text summarization were developed such as “google/pegasus-pubmed” and “google/bigbird-pegasus-large-pubmed”. RoBERTa, Robustly Optimized BERT Approach, is an improved version of BERT trained on a bigger corpus of text with some key optimizations, which led to the creation of Longformer [21], a transformer-based model, that can handle longer texts with its Encoder-Decoder variant for text-to-text generation “allenai/led-base-16384” and “led-large-16384-arxiv” [22]. Despite these advances, the field of ATS quickly moved towards decoder-only architectures which are at the basis of LLMs, able to capture semantic relations with higher flexibility and specificity. LLMs can be classified as (i) general-purpose models, which leverage their broad domain knowledge for a variety of NLP tasks, (ii) reasoning-oriented models, characterized by a logical understanding of the text through iterative chain-of-thought processing and instruction tuning [23], and (iii) domain-specific ones, designed to address specific tasks. Several families of LLMs have been developed, from the first GPT-1 [24] to the recently released reasoning-oriented GPT-5 series (Nano,

Mini, Full) and GPT:OSS, OpenAI GPT series models that are all pre-trained on large-scale text corpora in a self-supervised way. Similarly, Anthropic Claude Models are built on transformer architecture, trained through a Constitutional AI approach [25]. This family also includes a series of reasoning models such as Claude Sonnet-4, Opus-4 and Opus-4-1. Meta Llama family, where Llama 3 is the most capable model of the family up to now, comprises some domain-specific adaptations like OpenBioLLM-Llama-3, a variant of Meta's Llama-3 trained on a large corpus of high-quality biomedical data and medllama2, a medical language model built on Meta's LLaMA 2 architecture. Google and Microsoft developed a series of lightweight models such as Google Gemma series [26], with Gemma3 as its latest and most powerful reasoning model and the Microsoft Phi series, which comprises Phi-4-reasoning and Phi-4-mini-reasoning. Notably, Microsoft developed BioGPT [27], a model built on the GPT architecture and specifically fine-tuned on the biomedical domain. Other models such as Granite 4.0, a reasoning model of the IBM's Granite series and Magistral, the first reasoning model of the Mistral family have also been released. Remarkably, Mistral developed Biomistral, an open-source model pretrained on PubMed Central data. Moreover, Alibaba Cloud's introduced the Qwen 3 series as an open-source LLM family, where recently, SciLitLLM has been further developed as a specialized model for scientific literature understanding based on Qwen2.5 and trained through continual pre-training (CPT) and supervised fine-tuning (SFT) on scientific literature [28]. Lastly, DeepSeek has developed reinforcement learning (RL)-driven reasoning models, which are cost-effective and efficient [29] and APERTUS, Switzerland's first large-scale open, multilingual language model has been developed as an open-source model where the entire development process is openly accessible and fully documented.

To the best of our knowledge, no comprehensive evaluation and benchmarking of the different text summarizations for biomedical texts have been performed so far. The aim of this study was therefore to assess the text summarization performance of a number of models using a generated gold-standard dataset of biomedical abstracts and highlight sections of journals from the biomedical domain. We highlight strengths and limitations of each model to ultimately provide insights for accelerating knowledge discovery in molecular sciences.

2. Materials and Methods

2.1. Gold-Standard Dataset

We generated a gold-standard benchmarking dataset of 1,000 biomedical peer-reviewed articles from *ScienceDirect* and *Cell Press* - as these publishers provide a standardized *Highlights* section for each publication [30,31]. This section provides concise bullet points that capture the main findings of each article. These served as the reference summaries in our evaluation, while the corresponding abstracts were used as input texts for the summarization.

Articles were collected systematically across a variety of journals to ensure coverage of different fields within molecular sciences such as drug discovery, genomics, proteomics, biotechnology, and biochemistry. We included 50 articles from 20 different journals from the two publishers resulting in 1,000 papers as given in Table 1.

Table 1. Overview of journals in the gold-standard dataset.

Publisher	Journal
ScienceDirect	Drug Discovery Today
ScienceDirect	Journal of Molecular Biology
ScienceDirect	FEBS Letters
ScienceDirect	Journal of Biotechnology
ScienceDirect	Gene
ScienceDirect	Genomics
ScienceDirect	Journal of Proteomics
ScienceDirect	The International Journal of Biochemistry & Cell Biology
ScienceDirect	Cytokine
ScienceDirect	Developmental Cell
Cell	Cell
Cell	Cancer Cell
Cell	Cell Chemical Biology
Cell	Cell Genomics
Cell	Cell Host & Microbe
Cell	Cell Metabolism
Cell	Cell Reports
Cell	Cell Reports Medicine
Cell	Cell Stem Cell
Cell	Cell Systems

This setup provides standardized pairs of abstracts and reference summaries that can be directly used for evaluating automatic summarization methods. 124
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2.2. Summarization Methods

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We evaluated 62 summarization models, ranging from simple frequency-based algorithms to state-of-the-art small- and large language models (SLMs & LLMs) as listed in Table 2. 127
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The summarization models were grouped into five categories: 130

1. Traditional models: We included two traditional extractive models that served as a baseline for all of the newer more complex models: a simple frequency-based approach and TextRank [9]. 131
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2. Encoder-Decoder models: We included a set of pre-trained encoder-decoder models, which are available through the HuggingFace library: BART (base and large) [16], T5 (base and large) [32], mT5 [33], and a variety of PEGASUS models [20]. These models are often applied for abstractive summarization and represent well-established neural systems within our benchmark. 134
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3. General-purpose models: We also evaluated a range of widely used LLMs and SLMs designed for broad application, with SLMs being defined as <10 B parameters [34]. This group includes models such as Gemma [26], Granite [35], LLaMA [36], Mistral [37], Phi [38,39], GPT [40,41], Claude [42], and Apertus [43], which represent the current landscape of general-purpose systems. 139
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4. Reasoning-oriented models: Both LLMs and SLMs with a focus on advanced reasoning capabilities were categorized as reasoning-oriented models. This group includes models from the DeepSeek-R1 family [44], Qwen [45], more GPT models such as GPT-oss [46] and GPT-5 [47], Magistral [48], and some additional Claude models. Their design emphasizes multi-step problem solving and allowed us to explore whether reasoning affects summarization performance. 144
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5. Domain-specific models: To assess whether domain adaptation improves summarization quality, we included both LLMs and SLMs which are fine-tuned on sci- 150
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tific/biomedical data or on summarization such as PEGASUS and BigBird models fine-tuned on PubMed data (pegasus-pubmed & bigbird-pegasus-large-pubmed), LED [21] (arXiv-tuned), BioGPT [49], MedLLaMA2 [50], OpenBioLLM [51], BioMistral [52], and SciLitLLM1.5 models [53].

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155**Table 2.** Overview of summarization methods/models evaluated in this study, organized by category.

Category	Methods/Models
Traditional models	textrank; frequency
Encoder-Decoder models	facebook/bart-base; facebook/bart-large-cnn; google/t5/t5-base; google/t5/t5-large; cse-buetnlp/mT5_multilingual_XLSum; google/pegasus-xsum; google/pegasus-cnn_dailymail; google/pegasus-large
General-purpose SLMs	gemma3:270M; gemma3:1b; gemma3:4b; PetrosStav/gemma3-tools:4b; granite3.3:2b; granite3.3:8b; granite4:tiny-h; granite4:small-h; granite4:micro; granite4:micro-h; llama3.1:8b; llama3.2:1b; llama3.2:3b; mistral:7b; phi3:3.8b; gpt-4o-mini; chat_swiss-ai/Apertus-8B-Instruct-2509
General-purpose LLMs	gemma3:12b; mistral-nemo:12b; mistral-small3.2:24b; mistral-small-2506; mistral-medium-2505; mistral-large-2411; phi4:14b; gpt-3.5-turbo; gpt-4o; gpt-4.1; gpt-4.1-mini; claude-3-5-haiku-20241022
Reasoning-oriented SLMs	deepseek-r1:1.5b; deepseek-r1:7b; deepseek-r1:8b; qwen3:4b; qwen3:8b;
Reasoning-oriented LLMs	deepseek-r1:14b; gpt-oss:20b; gpt-5-nano-2025-08-07; gpt-5-mini-2025-08-07; gpt-5-2025-08-07; claude-sonnet-4-20250514; claude-opus-4-20250514; claude-opus-4-1-20250805; magistral-medium-2509
Domain-specific SLMs	google/pegasus-pubmed; google/bigbird-pegasus-large-pubmed; led_large_16384_arxiv_summarization; completion_microsoft/biogpt; medllama2:7b; chat_aaditya/OpenBioLLM-Llama3-8B; conversational_BioMistral/BioMistral-7B; chat_UniSMART/SciLitLLM1.5-7B
Domain-specific LLMs	chat_Uni-SMART/SciLitLLM1.5-14B

With this selection, we covered models of different sizes and release periods, ensuring that both widely adopted systems and recent architectures were represented. Extraordinarily large models, such as LLaMA 3.1 405B, were not considered because their resource demands exceed what is practical for typical summarization pipelines.

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These 62 diverse models were all tasked with generating summaries for each of the 1,000 abstracts in the dataset, resulting in 50,000 generated summaries available for evaluation.

2.3. Prompt Design

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To ensure comparability across models, we prompted all summarization systems with the same task description. The prompt instructed the models to generate concise summaries focused on the main findings of each publication while excluding unnecessary background or methodological detail. Each model received the publication title and abstract as input and was asked to produce an output of approximately 15–100 words. If the abstract did

not contain any substantive results or conclusions, the model was instructed to return the predefined token INSUFFICIENT_FINDINGS.

The exact prompt used for all models was as follows:

Summarize the provided publication (title and abstract) in 15-100 words.

Key requirements:

- Identify main findings, results, or contributions
- Preserve essential context and nuance
- Exclude background, methods unless crucial to conclusions
- Write concisely and objectively
- Avoid repetition and unnecessary qualifiers

If no substantial findings exist, respond: 'INSUFFICIENT_FINDINGS'

2.4. Evaluation Metrics

As there is no single metric that can fully reflect summary quality, especially in the biomedical field where both coverage of key information and factual correctness are critical, we used a multitude of metrics grouped into two categories: traditional surface-level metrics and embedding-based metrics. By combining all these metrics into one final overall score, we ended up with a balanced benchmark value that reflects summary quality.

2.4.1. Surface-level Metrics

Surface-level metrics compare the generated summaries with the reference summaries mainly at the word or phrase level. While they do not capture meaning beyond surface overlap, they remain common metrics in summarization research and provide a simple foundation for evaluation. We used three ROUGE variants (ROUGE-1, ROUGE-2, ROUGE-L) [54], BLEU [55], and METEOR [56]. ROUGE-1 and ROUGE-2 measure how many unigrams (single words) or bigrams (word pairs) from the reference appear in the generated output, while ROUGE-L identifies the longest sequence of words shared between the two. BLEU calculates how many n-grams in the output also occur in the reference, but it emphasizes precision over recall and applies a brevity penalty to counteract the tendency toward overly short summaries. METEOR extends n-gram matching by also considering word stems and synonyms, which makes it more tolerant to variations in wording. Together, these metrics offer a simple but transparent point of reference.

2.4.2. Embedding-based Metrics

To capture similarity beyond surface-level word overlap, we included a set of embedding-based metrics built on pre-trained transformer models. These methods generate vector representations of text, which allow them to capture similarity in meaning rather than just word overlap. We employed RoBERTa [57] and DeBERTa [58], two transformer-based models with strong performance across natural language processing tasks. In the context of summarization evaluation, they can be used to judge whether two summaries capture the same content even if phrased differently.

We also included all-mpnet-base-v2 [59], a transformer model fine-tuned for sentence similarity. Unlike RoBERTa and DeBERTa, which are primarily general-purpose encoders, MPNet was trained with a focus on alignment at the sentence-level. This focus makes it a useful complement to the other metrics, as it is particularly sensitive to whether the overall sense of a reference summary is preserved in the system output.

Finally, to evaluate factual consistency, we applied AlignScore [60], a metric designed to test whether the statements in a generated summary are supported by the source text. In

contrast to the other metrics, AlignScore thus compares the output to the input text itself (i.e. the publication abstract) instead of the reference summary (i.e. the Highlights section), as factual accuracy can only be assessed relative to the original input text. This addition ensures that our evaluation is sensitive to errors and hallucinations that might otherwise be overlooked.

2.4.3. Ranks Calculation

For each of the evaluation metrics, ranks were calculated by assigning rank 1 to the lowest metric value, reflecting the best-performing model. Different weights were then given to each score (Table 3) to compute a weighted overall score by multiplying each metric rank by its weight and then summing all weighted ranks together. Thus, the overall performance rank was built by prioritizing the semantic metrics (RoBERTa and DeBERTa), which better reflect true summary quality, over the lexical (ROUGE, BLEU, METEOR) and alignment-based (all-mpnet-base-v2, AlignScore) ones.

Table 3. Overview of the assigned weights for each evaluation metric.

Evaluation Metric	Weight	Percentage
RoBERTa	0.25	
DeBERTa	0.25	50%
ROUGE-1	0.07	
ROUGE-2	0.07	
ROUGE-L	0.05	30%
METEOR	0.06	
BLEU	0.05	
all-mpnet-base-v2	0.11	
AlignScore	0.09	20%

2.4.4. Performance Metrics

In addition to summary quality, we also considered some practical aspects of model performance:

- Execution time records the average time required to generate summaries, which is critical when processing large datasets.
- Length compliance (% within bounds) measures how often the generated summaries fall within the target length range specified in the prompt. It reflects a model's ability to follow explicit output-length instructions as it penalizes overly short or excessively long responses.
- Insufficient findings describe how often a model returned the predefined token 'INSUFFICIENT_FINDINGS' instead of producing a summary, capturing cases where it concluded the input did not contain substantive findings. Summaries that were clearly nonsensical or contained no meaningful content were also flagged as 'INSUFFICIENT_FINDINGS' during post-processing.

These measures complement the quality metrics in some evaluations by addressing whether a method is not only accurate but also feasible to use in practice.

2.5. Benchmarking Framework

The benchmark was conducted using Python 3.12. Gold standard data were retrieved from open-access publications published by ScienceDirect and Cell Press through manual extraction of titles, abstracts, and highlight sections, along with metadata including publication URLs, identifiers, section types, and article types where available. All data were stored in machine-readable JSON format.

The framework was implemented using the Python standard library supplemented by several specialized packages: pandas [61] for data import and export, scikit-learn [62] for computing cosine similarities of embeddings and TF-IDF vectors, networkx [63] for graph construction and PageRank algorithm [64]. Additional evaluation metrics were computed using NLTK [65] for METEOR and BLEU scores, ROUGE-score, BERT-score [66], AlignScore, and sentence-transformers [67] with the all-mpnet-base-v2 model.

Communication with proprietary closed-source LLMs was facilitated through the official Python APIs provided by Anthropic, Mistral AI, and OpenAI. Local LLM execution was performed on a workstation equipped with a NVIDIA RTX A4000 GPU (16GB VRAM) running Ollama as a backend service, accessed through its Python API along with the transformers library [68].

All LLMs were configured with a temperature parameter of 0.2 to optimize reproducibility while avoiding completely deterministic outputs. For the latest generation of OpenAI models featuring adaptive reasoning capabilities, the configuration was set to `text.verbosity = low` and `reasoning.effort = minimal`. The full set of parameters and prompts are documented in the `config.py` file in the GitHub repository.

2.6. Data Availability

The complete source code, documentation, gold standard dataset, and processed results are available at:

<https://www.github.com/Delta4AI/LLMTextSummarizationBenchmark>.

3. Results

Our benchmark results offer a comparative view of summarization performance across all evaluated models. We first present overall rankings, followed by comparisons between the different model groups. Additionally, we examine results on individual metrics, runtime performance, and correlations between the evaluation metrics used.

3.1. Overall Model Performance

Based on the Performance outcomes of the models shown in Figure 1, the ones belonging to the Mistral family occupied the top position of the ranking, achieving good ranks across nearly all surface-level metrics (ROUGE-1, ROUGE-2, ROUGE-L, METEOR, BLEU) and on most embedding-based measures (RoBERTa, DeBERTa, all-mpnet-base-v2, AlignScore). In detail, according to the Performance rank, mistral-medium-2505 ranks first, followed by mistral-small-2506, mistral-small-3.2:24b and mistral-large-2411.

On the other hand, by looking at the lowest-ranked models, we can identify some models from the Pegasus family such as pegasus-xsum, pegasus-pubmed and bigbird-pegasus-large-pubmed, with the last one being ranked as the worst-performing model. Moreover, some models of the GPT family, such as OpenBioLLM-Llama3-8B and biogpt, as well as a model from the T5 family, multilingual_XLSum, show poor performance across all the metrics.

Considering the models categories, among the 10 top ranked models, four are General-purpose LLMs, two General-purpose SLMs, three Reasoning-oriented LLMs and one Reasoning-oriented SLM. Remarkably, when considering the top half of the ranking, from position 10 to 32, the same categories seen in the top 10 are present apart from a single Domain-specific LLM ranked at 20 (SciLitLLM1.5-14B). All the General-purpose LLMs are only present in this half of the ranking. In contrast, in the lower half of the ranking, where models start to perform poorly across most metrics, the majority are Reasoning-oriented SLMs, encoder-decoder models and Traditional models. The best and worst

models according to their model category are reported in Table 4, while the best and worst according to the model family are reported in Table 5.

Table 4. Overview of the best- and worst-performing models by category. Domain-specific LLMs are not reported, as only a single model was available.

Category	Best Model	Rank	Worst Model	Rank
General-purpose SLMs	Granite3.3:8b	9	Phi3:3.8b	45
General-purpose LLMs	Mistral-medium-2505	1	Mistral-nemo:12b	30
Reasoning-oriented SLMs	GPT-4o-mini	6	Deepseek-r1:8b	50
Reasoning-oriented LLMs	GPT-4o	5	GPT-5	41
Domain-specific SLMs	SciLitLLM1.5-7B	37	bigbird-pegasus-large-pubmed	62

Table 5. Overview of the best- and worst-performing models by family. The Apertus models are not reported, as only a single model was available.

Family	Best Model	Rank	Worst Model	Rank
Qwen	SciLitLLM1.5-14B	20	Qwen3:4b	43
Gemma	Gemma3-tools:4b	10	Gemma3:270M	42
Granite	Granite3.3:8b	9	Granite3.3:2b	28
LLaMA	Llama3.2:3b	26	OpenBioLLM-Llama3-8B	61
Mistral	Mistral-medium-2505	1	BioMistral-7B	38
Phi	Phi4:14b	23	Phi3:3.8b	45
DeepSeek	Deepseek-r1:14b	34	Deepseek-r1:8b	50
GPT	GPT-4o	5	BioGPT	59
Claude	Claude-sonnet-4	8	Claude-opus-4-1	33

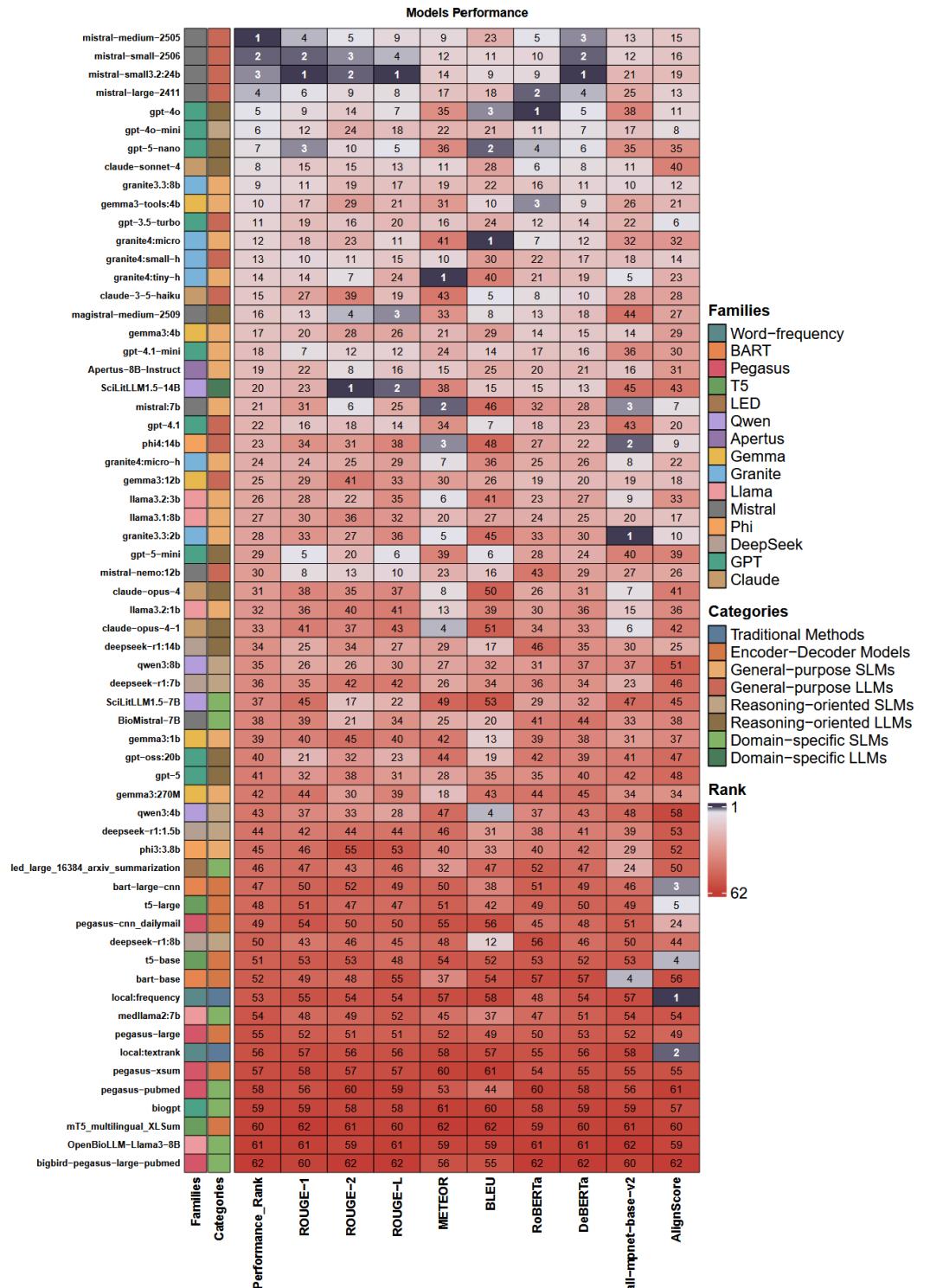


Figure 1. Overview of the performance of all evaluated models across all surface-level and embedding-based metrics. Each row corresponds to one model, and each column to a specific metric, with lower ranks indicating better performance. In addition to individual model names, the figure also indicates each model's family (e.g., GPT, DeepSeek, Gemma, Granite) and its broader category (e.g., encoder-decoder, general-purpose SLMs, reasoning-oriented LLMs). Models are sorted by their weighted average rank across metrics called Performance_Rank where lower ranks indicate better performance.

3.2. Group Comparisons

Figure 2 summarizes the average performance of the eight model categories based on the overall Metric Mean Score. General-purpose LLMs achieved the highest mean

score (0.526), followed closely by general-purpose SLMs (0.519) and reasoning-oriented LLMs (0.515). Traditional extractive models and Encoder-decoder models performed considerably lower, with mean scores of 0.451 and 0.446, respectively. The Domain-specific SLMs showed the weakest overall performance (0.423), whereas the Domain-specific LLMs achieved a higher score (0.513; single model).

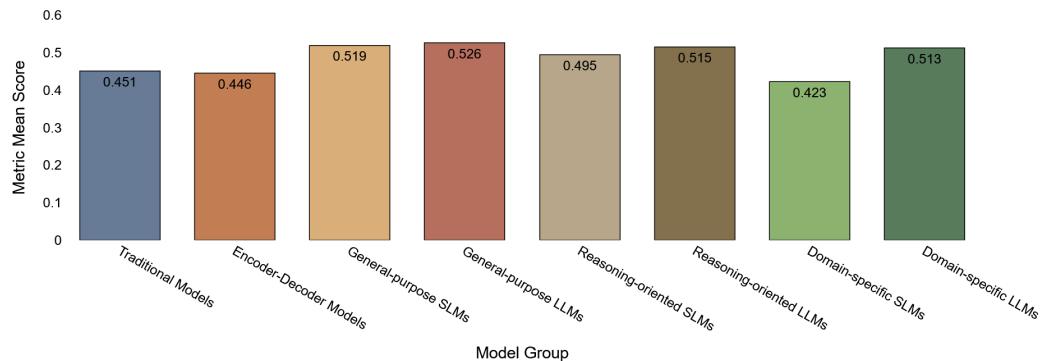


Figure 2. Average Metric Mean Score across the eight model categories. The figure highlights clear performance differences between categories, with general-purpose LLMs performing best overall, followed by general-purpose SLMs and reasoning-oriented LLMs. Traditional, encoder-decoder, and Domain-specific SLMs achieved notably lower scores.

3.2.1. SLMs vs. LLMs

To further analyze differences between small and large language models, we compared the performance of SLMs and LLMs within both the general-purpose and reasoning-oriented groups (Figure 3). In both categories, LLMs achieved slightly higher overall Metric Mean Scores and generally performed better on surface-level and embedding-based metrics. Differences in execution time were minimal, although as expected SLMs perform slightly better here, while compliance with word-length bounds favored LLMs in the general-purpose group but SLMs in the reasoning-oriented group. The comparison for domain-specific models is not shown here, as this category includes only a single LLM, which prevents a meaningful comparison.

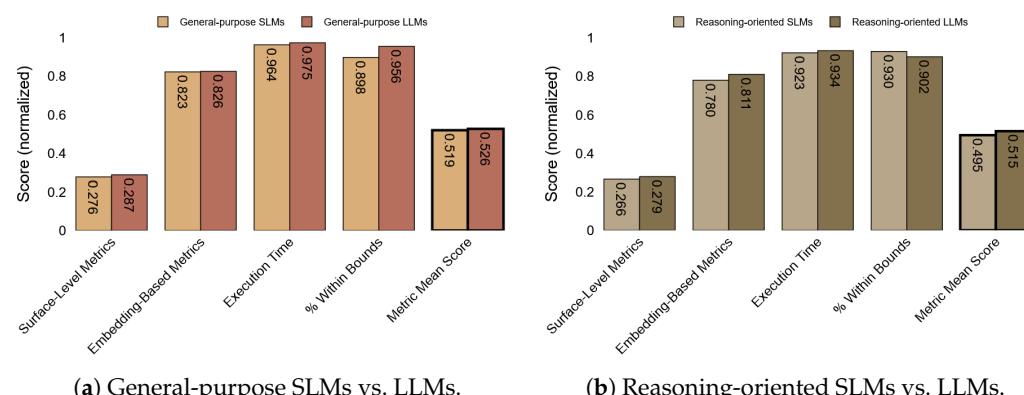
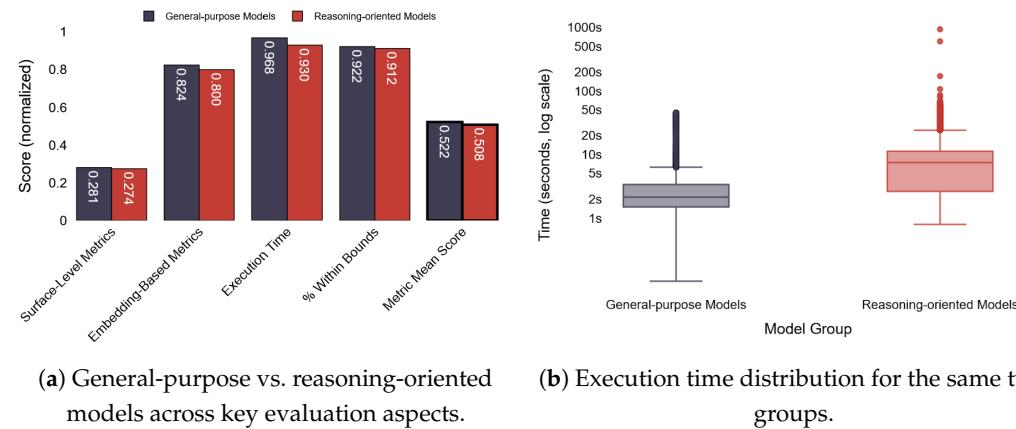


Figure 3. (a) Comparison between general-purpose SLMs and LLMs across key evaluation metrics. (b) Comparison between reasoning-oriented SLMs and LLMs. In both groups, LLMs achieved slightly higher overall Metric Mean Scores, while SLMs occasionally performed better on individual metrics.

3.2.2. General-purpose Models vs. Reasoning-oriented Models

Figure 4a compares the two largest and most competitive groups (general-purpose and reasoning-oriented models) across multiple evaluation aspects. The comparison includes both SLMs and LLMs within each group. Overall, general-purpose models achieved slightly

higher scores in all measured categories, including surface-level metrics, embedding-based metrics, execution time, compliance with word-length bounds, and overall Metric Mean Score. The largest difference was observed in execution time, where general-purpose models produced summaries more efficiently on average. Figure 4b provides a more detailed view of these runtime differences. The performance gap in quality metrics was smaller but consistent, with general-purpose models maintaining a slight advantage across both surface-level and embedding-based evaluations.



(a) General-purpose vs. reasoning-oriented models across key evaluation aspects.

(b) Execution time distribution for the same two groups.

Figure 4. (a) Comparison between general-purpose and reasoning-oriented models across key evaluation metrics. General-purpose models achieved higher scores across all categories, including surface-level and embedding-based metrics, execution time, compliance with word-length bounds, and overall Metric Mean Score. (b) Distribution of execution times for the same groups, showing that general-purpose models produced summaries more efficiently and with lower variability.

3.3. Metric Correlations

To examine how the different evaluation metrics relate to each other, we computed pairwise Pearson correlation coefficients across all models (Figure 5).

Strong positive correlations were observed among the surface-level metrics (ROUGE-1, ROUGE-2, ROUGE-L, METEOR, and BLEU). ROUGE variants were almost identical in their behavior ($\rho > 0.9$), while BLEU and METEOR showed slightly weaker but still substantial alignment with the ROUGE measures.

Most embedding-based metrics (RoBERTa, DeBERTa, and all-mpnet-base-v2) also showed very high internal consistency ($\rho > 0.8$), which reflects their shared focus on semantic similarity beyond surface-level overlap. When compared with the surface-level metrics, correlations were moderate to strong ($\rho \approx 0.7\text{--}1.0$), indicating that the two categories capture related but not identical dimensions of summary quality.

AlignScore correlated only moderately with the other metrics ($\rho \approx 0.4\text{--}0.7$), which can be attributed to its different point of reference, as it compares generated summaries directly with the source abstracts instead of the reference summaries used by the other metrics.

Overall, these relationships show that the various metrics are broadly consistent while still providing complementary perspectives. This supports the use of an aggregated “Metrics Mean Score” as a balanced indicator of overall summarization performance.

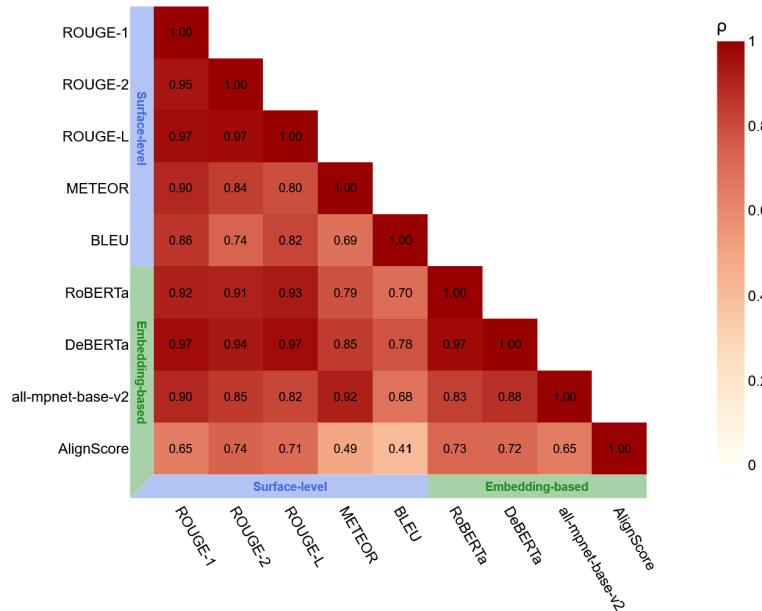


Figure 5. Correlation matrix of all evaluation metrics. Each cell in the matrix represents the Pearson correlation coefficient (ρ) between two metrics based on their mean scores across models. Surface-level and most embedding-based metrics show strong internal consistency, while AlignScore exhibits lower correlations due to its distinct focus on factual consistency with the source abstracts.

3.4. Qualitative Analysis: Case Study

To illustrate how concept coverage differs between models beyond aggregate metrics, we examine two summaries of a biomedical research article [doi:10.1016/j.cell.2025.05.026] against publisher-provided highlights. The source article, titled “*A percolation phase transition controls complement protein coating of surfaces*”, includes four key highlights: (H1) The complement protein network has a switch-like response when attacking surfaces; (H2) Complement “decides” to coat surfaces if surface protein spacing is below a threshold; (H3) Complement’s threshold decision-making arises from a percolation phase transition; (H4) Complexity science shows how complement makes discrete decisions attacking surfaces.

The generated summaries are as follows:

- **mistral_medium-2505:** “This study reveals that the complement system, a network of blood proteins, exhibits a sharp activation threshold based on the surface density of attachment points on materials. This threshold behavior, observed across scales from nanoparticles to macroscale pathologies, arises from a percolation-type phase transition in a minimal subnetwork of complement proteins. The findings suggest that this critical transition acts as a switch, determining whether the complement system will interact with and initiate inflammation against a material.”
- **SciLitLLM1.5-14B:** “A sharp threshold for complement activation upon varying a fundamental material parameter, the surface density of potential complement attachment points, was experimentally demonstrated and computationally explained.”

Table 6 summarizes the concept-level coverage and overall performance for both models. While both models capture the surface density threshold (H2), the lower-performing model omits the mechanistic explanation (H3) and only partially conveys the behavioral characteristics (H1, H4), resulting in substantially lower concept coverage and semantic alignment. The overall performance scores, derived using the weighted metric aggregation introduced in Section 2.4.3, further reflect this difference, with **mistral_medium-2505** achieving 0.619 compared to 0.560 for **SciLitLLM1.5-14B**.

Table 6. Concept coverage analysis of model-generated summaries. Symbols: ✓ = fully covered; ~ = partially covered; ✗ = not covered. Overall performance scores are derived using the weighted metric aggregation described in Section 2.4.3.

Reference Concept	mistral_medium-2505	SciLitLLM1.5-14B
H1: Switch-like response	✓	~
H2: Surface density threshold	✓	✓
H3: Percolation phase transition	✓	✗
H4: Discrete decision-making	✓	~
Coverage Score	4.0 / 4.0	1.5 / 4.0
Semantic Similarity ^a	0.946	0.731
Overall Performance Score	0.619	0.560

^aCosine similarity to highlights (all-mpnet-base-v2).

4. Discussion

The benchmarking analysis revealed clear performance differences between the evaluated summarization approaches. Overall, general-purpose large language models (LLMs) achieved the highest summarization quality across all surface-level and embedding-based metrics, followed closely by general-purpose small language models (SLMs) and reasoning-oriented LLMs. In contrast, domain-specific models, encoder-decoder architectures such as T5 and PEGASUS, and traditional extractive methods like TextRank all reached noticeably lower performance levels. These results highlight the clear progression from extractive and encoder-decoder approaches toward transformer-based models, while also showing that domain-specific fine-tuning alone does not necessarily lead to improved summarization quality.

4.1. Model Group Comparisons

To understand the causes of the observed performance differences, the models were compared by architecture, size, and domain focus. This analysis examines how model scale, reasoning ability, and domain specialization influence summarization quality in biomedical texts. The next sections discuss these aspects in detail by comparing large and small language models, general-purpose and domain-specific models, and general-purpose and reasoning-oriented models, referring to Figure 1.

4.1.1. General-purpose Large vs. Small Language Models (LLMs vs. SLMs)

By comparing the overall performance of SLMs and LLMs, even among the top 10 of the best-performing models the majority are LLMs. This is likely due to their huge number of parameters which allow them to better understand the complex context typical for biomedical literature. While very small models, like Gemma3:270M, can indeed lack the capacity to handle this complexity, SLMs remain competitive, with some models even outperforming certain LLMs. This may be because smaller datasets are often more curated and of higher quality compared to the large amount of data required to train a big model [69].

Interestingly, medium-sized models in the range of approx. 20-70B parameters (e.g. the Mistral family), appear to be more performant than larger proprietary ones. These models seem to reach an optimal compromise about number of parameters and overall performance where additional parameters could disrupt this equilibrium, leading to potentially over-fitting or plateauing performance [70].

4.1.2. General-purpose vs. Domain-specific Models

As discussed in the introduction section, domain-specific models have been developed over time with the aim of improving model ability for a specific task. However, in this article, we found that overall General-purpose models outperform both domain-specific models specialized in the biomedical domain and the one specialized for text summarization, regardless of model size. A possible explanation for this behavior is that domain-specific models fine-tuned on biomedical text, might be better for learning and understanding the complex biomedical terminology or lexical patterns but might fail in the specific summarization task. On the other hand, models specifically designed for text summarization might be good at summarizing in general but fail at capturing the complex biomedical meaning. That is why generalist models, leveraging their broad knowledge, seem to perform better [71]. Additionally, domain-specific models can “forget” the general knowledge that was acquired during the pre-training phase, experiencing a phenomenon called “catastrophic forgetting”, which represents an issue when the task requires both domain-specific knowledge, the biomedical knowledge, and context understanding, for text summarization [72].

4.1.3. General-purpose vs Reasoning-oriented Models

Even though some reasoning-oriented models ranked among the top 10 of the best performing models, most of them were positioned in the middle of the ranking as moderate performing models. This can be explained by the intrinsic multi-step logical reasoning nature of these models, that while it can be advantageous for tasks that require breaking problems down into sequential steps like for mathematics or coding, it can be not ideal for text summarization that require semantic compression and factual grounding instead [73].

4.2. Evaluation and Metric Considerations

The evaluation framework combined surface-level, embedding-based, and factual consistency metrics to capture complementary aspects of summarization quality. Surface-level metrics such as ROUGE, BLEU, and METEOR primarily measure lexical overlap with the reference summaries, while embedding-based metrics including RoBERTa, DeBERTa, and MPNet assess semantic similarity and paraphrasing ability. AlignScore adds a distinct perspective by evaluating factual consistency between the generated summary and its source abstract. Unlike other metrics, it directly compares the summary with the input rather than with the human-written Highlights section. This design enables AlignScore to evaluate factual faithfulness to the source material instead of measuring the similarity to the reference summary.

While the correlation analysis indicated broad agreement among most metrics, AlignScore showed weaker alignments with the others, which emphasizes that factual consistency represents a distinct dimension of summarization quality. The strong performance of extractive approaches such as the frequency-based and TextRank models illustrates this difference: by retaining sentences from the abstract almost verbatim, these models naturally preserve factual accuracy and therefore achieve high AlignScore values, despite weaker results on other metrics.

Nevertheless, using AlignScore in this benchmark was intentional as factual grounding is an essential requirement in scientific text summarization. Models that generate fluent or semantically similar summaries may still introduce factual inaccuracies or exclude key information. Including AlignScore therefore ensures that the benchmark considers both linguistic quality and factual reliability.

4.3. Model Access Methods and API Heterogeneity

Model access methods varied across the evaluation due to differing API capabilities and requirements. HuggingFace models were accessed through their supported interfaces: the pipeline API (task="summarization") where available, or chat/completion formats for models that did not support the pipeline approach. Ollama models required use of the generate endpoint with merged prompts, while OpenAI, Anthropic, and Mistral models each mandated their respective provider-specific APIs (responses.create, messages.create, and chat.complete) with distinct message structures. We applied hyperparameter normalization where possible, though API-level constraints prevented full standardization. For example, GPT-5 does not support temperature control, instead offering only reasoning-specific parameters. Additionally, proprietary middleware layers may transform requests and responses in undocumented ways, potentially affecting outputs independently of the underlying model architectures. These necessary methodological variations warrant consideration when interpreting performance differences across models.

4.4. Limitations and Future Work

This benchmark focuses on a single summarization task: generating concise, highlight-style summaries from biomedical abstracts. This setup provides a clear and well-defined evaluation framework, but the findings may not fully extend to other forms of scientific or biomedical summarization, including full-length articles, clinical trial data, or lay-oriented summaries. And the rapid pace of progress in large language models means that the results reflect a specific snapshot in time and may change as newer architectures and model versions become available.

Another limitation lies in the exclusive reliance on automatic evaluation metrics. Although combining surface-level, embedding-based, and factual measure offers a broad view, human assessment would provide a more nuanced understanding of readability, coherence, and factual correctness. Future work could therefore extend this benchmark by integrating expert-based evaluations, exploring alternative summarization tasks, and including emerging model families as they are released.

4.5. Practical Implications and Applications

The results of this benchmark provide useful guidance for selecting summarization models in biomedical and scientific settings. The strong performance of general-purpose LLMs indicates that broad, diverse pretraining is often more advantageous than narrow domain adaptation when dealing with unseen scientific content.

Another key consideration is the trade-off between output quality and processing efficiency. While LLMs achieved the highest overall scores, SLMs deliver competitive results at substantially lower computational cost, which makes them especially attractive for large-scale or resource-constrained applications. Choosing between large and small models therefore depends not only on desired output quality but also on the intended scale of summarization.

Overall, the findings suggest that general-purpose LLMs currently offer the most reliable and practical choice for biomedical summarization. Their consistent performance across evaluation criteria demonstrates that broad generalization outweighs the marginal gains from more narrowly specialized or fine-tuned approaches, many of which are not primarily optimized for summarization.

5. Conclusions

Draft: For scientific text summarization specifically, models need sufficient capacity to understand domain terminology and complex relationships without the computational overhead and potential overfitting of massive proprietary systems.

The semantic comprehension and text generation strengths of general-purpose LLMs outweigh the multi-step reasoning capabilities that reasoning-oriented models bring to other domains

6. Patents

This section is not mandatory, but may be added if there are patents resulting from the work reported in this manuscript.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “Conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript.”, please turn to the [CRediT taxonomy](#) for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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Written informed consent for publication must be obtained from participating patients who can be identified (including by the patients themselves). Please state “Written informed consent has been obtained from the patient(s) to publish this paper” if applicable.

Data Availability Statement: We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required. Suggested Data Availability Statements are available in section “MDPI Research Data Policies” at <https://www.mdpi.com/ethics>.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI Multidisciplinary Digital Publishing Institute

DOAJ Directory of open access journals

TLA Three letter acronym

LD Linear dichroism

Appendix A

Appendix A.1

The appendix is an optional section that can contain details and data supplemental to the main text—for example, explanations of experimental details that would disrupt the flow of the main text but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data are shown in the main text can be added here if brief, or as Supplementary Data. Mathematical proofs of results not central to the paper can be added as an appendix.

Table A1. This is a table caption.

Title 1	Title 2	Title 3
Entry 1	Data	Data
Entry 2	Data	Data

Appendix B

All appendix sections must be cited in the main text. In the appendices, Figures, Tables, etc. should be labeled, starting with “A”—e.g., Figure A1, Figure A2, etc.

References

1. Zhang, Y.; Jin, H.; Meng, D.; Wang, J.; Tan, J. A Comprehensive Survey on Process-Oriented Automatic Text Summarization with Exploration of LLM-Based Methods, 2025, [\[arXiv:cs.AI/2403.02901\]](https://arxiv.org/abs/cs.AI/2403.02901).
2. Zhang, H.; Yu, P.S.; Zhang, J. A Systematic Survey of Text Summarization: From Statistical Methods to Large Language Models, 2024, [\[arXiv:cs.CL/2406.11289\]](https://arxiv.org/abs/cs.CL/2406.11289).
3. Rohil, M.K.; Magotra, V. An exploratory study of automatic text summarization in biomedical and healthcare domain. *Healthcare Analytics* **2022**, *2*, 100058. <https://doi.org/10.1016/j.health.2022.100058>.
4. Xie, Q.; Luo, Z.; Wang, B.; Ananiadou, S. A Survey for Biomedical Text Summarization: From Pre-trained to Large Language Models, 2023, [\[arXiv:cs.CL/2304.08763\]](https://arxiv.org/abs/cs.CL/2304.08763).
5. Luhn, H.P. The Automatic Creation of Literature Abstracts. *IBM J. Res. Dev.* **1958**, *2*, 159–165.
6. Edmundson, H.P. New Methods in Automatic Extracting. *J. ACM* **1969**, *16*, 264–285. <https://doi.org/10.1145/321510.321519>.

7. Robertson, S. Understanding Inverse Document Frequency: On Theoretical Arguments for IDF. *Journal of Documentation - J DOC* **2004**, *60*, 503–520. <https://doi.org/10.1108/00220410410560582>. 583
8. Reeve, L.H.; Han, H.; Nagori, S.V.; Yang, J.C.; Schwimmer, T.A.; Brooks, A.D. Concept frequency distribution in biomedical text summarization. In Proceedings of the Proceedings of the 15th ACM International Conference on Information and Knowledge Management, New York, NY, USA, 2006; CIKM '06, p. 604–611. <https://doi.org/10.1145/1183614.1183701>. 584
9. Mihalcea, R.; Tarau, P. TextRank: Bringing Order into Text. In Proceedings of the Proceedings of the 2004 Conference on Empirical Methods in Natural Language Processing; Lin, D.; Wu, D., Eds., Barcelona, Spain, 2004; pp. 404–411. 585
10. Shang, Y.; et al. Learning to rank-based gene summary extraction. *BMC Bioinformatics* **2014**, *15*, S10. <https://doi.org/10.1186/1471-2105-15-S12-S10>. 586
11. Erkan, G.; Radev, D.R. LexRank: Graph-based Lexical Centrality as Salience in Text Summarization. *Journal of Artificial Intelligence Research* **2004**, *22*, 457–479. <https://doi.org/10.1613/jair.1523>. 587
12. Afzal, M.; Alam, F.; Malik, K.M.; Malik, G.M. Clinical Context-Aware Biomedical Text Summarization Using Deep Neural Network: Model Development and Validation. *J Med Internet Res* **2020**, *22*, e19810. <https://doi.org/10.2196/19810>. 588
13. Almasoud, A.; Hassine, S.; Al-Wesabi, F.; Nour, M.; Hilal, A.; Al Duhamyim, M.; Hamza, A.; Motwakel, A. Automated Multi-Document Biomedical Text Summarization Using Deep Learning Model. *Computers, Materials & Continua* **2022**, *71*, 5800. <https://doi.org/10.32604/cmc.2022.024556>. 589
14. Vaswani, A.; Shazeer, N.; Parmar, N.; Uszkoreit, J.; Jones, L.; Gomez, A.N.; Kaiser, L.; Polosukhin, I. Attention Is All You Need, 2023, [arXiv:cs.CL/1706.03762]. 590
15. Devlin, J.; Chang, M.W.; Lee, K.; Toutanova, K. BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding, 2019, [arXiv:cs.CL/1810.04805]. 591
16. Lewis, M.; Liu, Y.; Goyal, N.; Ghazvininejad, M.; Mohamed, A.; Levy, O.; Stoyanov, V.; Zettlemoyer, L. BART: Denoising Sequence-to-Sequence Pre-training for Natural Language Generation, Translation, and Comprehension. *CoRR* **2019**, *abs/1910.13461*, [1910.13461]. 592
17. Yuan, H.; Yuan, Z.; Gan, R.; Zhang, J.; Xie, Y.; Yu, S. BioBART: Pretraining and Evaluation of A Biomedical Generative Language Model. In Proceedings of the Proceedings of the 21st Workshop on Biomedical Language Processing; Demner-Fushman, D.; Cohen, K.B.; Ananiadou, S.; Tsujii, J., Eds., Dublin, Ireland, 2022; pp. 97–109. <https://doi.org/10.18653/v1/2022.bionlp-1.9>. 593
18. Abinaya, S.; Vigil, M.; Keerthika, K.; Varshasri, R. Medical Text Summarization Using BART with LoRA-Based Parameter Efficient Fine Tuning **2024**. 594
19. Raffel, C.; Shazeer, N.; Roberts, A.; Lee, K.; Narang, S.; Matena, M.; Zhou, Y.; Li, W.; Liu, P.J. Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer, 2023, [arXiv:cs.LG/1910.10683]. 595
20. Zhang, J.; Zhao, Y.; Saleh, M.; Liu, P.J. PEGASUS: Pre-training with Extracted Gap-sentences for Abstractive Summarization, 2020, [arXiv:cs.CL/1912.08777]. 596
21. Beltagy, I.; Peters, M.E.; Cohan, A. Longformer: The Long-Document Transformer. *arXiv:2004.05150* **2020**. 597
22. Stebliaiko, O.; Shymkovych, V.; Kravets, P.; Novatskyi, A.; Shymkovych, L. Scientific article summarization model with unbounded input length. *Information, Computing and Intelligent systems* **2024**, pp. 150–158. <https://doi.org/10.20535/2786-8729.52024.314724>. 598
23. Plaat, A.; Wong, A.; Verberne, S.; Broekens, J.; van Stein, N.; Back, T. Multi-Step Reasoning with Large Language Models, a Survey, 2025, [arXiv:cs.AI/2407.11511]. 599
24. Radford, A.; Narasimhan, K. Improving Language Understanding by Generative Pre-Training. 2018. 600
25. Bai, Y.; Kadavath, S.; Kundu, S.; Askell, A.; Kernion, J.; Jones, A.; Chen, A.; Goldie, A.; Mirhoseini, A.; McKinnon, C.; et al. Constitutional AI: Harmlessness from AI Feedback, 2022, [arXiv:cs.CL/2212.08073]. 601
26. Team, G.; Kamath, A.; Ferret, J.; Pathak, S.; Vieillard, N.; Merhej, R.; Perrin, S.; Matejovicova, T.; Ramé, A.; Rivière, M.; et al. Gemma 3 Technical Report, 2025, [arXiv:cs.CL/2503.19786]. 602
27. Turbitt, O.; Bevan, R.; Aboshokor, M. MDC at BioLaySumm Task 1: Evaluating GPT Models for Biomedical Lay Summarization. In Proceedings of the Proceedings of the 22nd Workshop on Biomedical Natural Language Processing and BioNLP Shared Tasks; Demner-fushman, D.; Ananiadou, S.; Cohen, K., Eds., Toronto, Canada, 2023; pp. 611–619. <https://doi.org/10.18653/v1/2023.bionlp-1.65>. 603
28. Li, S.; Huang, J.; Zhuang, J.; Shi, Y.; Cai, X.; Xu, M.; Wang, X.; Zhang, L.; Ke, G.; Cai, H. SciLitLLM: How to Adapt LLMs for Scientific Literature Understanding, 2025, [arXiv:cs.LG/2408.15545]. 604
29. Wang, C.; Kantarcioglu, M. A Review of DeepSeek Models' Key Innovative Techniques, 2025, [arXiv:cs.LG/2503.11486]. 605
30. Elsevier. Highlights, 2024. Accessed: 2025-08-07. 606
31. Cell Press. Final Submission: Other Components: Highlights, 2024. Accessed: 2025-08-07. 607
32. Raffel, C.; Shazeer, N.; Roberts, A.; Lee, K.; Narang, S.; Matena, M.; Zhou, Y.; Li, W.; Liu, P.J. Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer. *Journal of Machine Learning Research* **2020**, *21*, 1–67. 608

33. Hasan, T.; Bhattacharjee, A.; Islam, M.S.; Mubashir, K.; Li, Y.F.; Kang, Y.B.; Rahman, M.S.; Shahriyar, R. XL-Sum: Large-Scale Multilingual Abstractive Summarization for 44 Languages. In Proceedings of the Findings of the Association for Computational Linguistics: ACL-IJCNLP 2021, Online, 2021; pp. 4693–4703. 636
- 637
- 638
34. Belcak, P.; Heinrich, G.; Diao, S.; Fu, Y.; Dong, X.; Muralidharan, S.; Lin, Y.C.; Molchanov, P. Small Language Models are the Future of Agentic AI, 2025, [arXiv:cs.AI/2506.02153]. 639
- 640
35. Mishra, M.; Stallone, M.; Zhang, G.; Shen, Y.; Prasad, A.; Soria, A.M.; Merler, M.; Selvam, P.; Surendran, S.; Singh, S.; et al. Granite Code Models: A Family of Open Foundation Models for Code Intelligence, 2024, [arXiv:cs.AI/2405.04324]. 641
- 642
36. Grattafiori, A.; Dubey, A.; Jauhri, A.; Pandey, A.; Kadian, A.; Al-Dahle, A.; Letman, A.; Mathur, A.; Schelten, A.; Vaughan, A.; et al. The Llama 3 Herd of Models, 2024, [arXiv:cs.AI/2407.21783]. 643
- 644
37. Jiang, A.Q.; Sablayrolles, A.; Mensch, A.; Bamford, C.; Chaplot, D.S.; de las Casas, D.; Bressand, F.; Lengyel, G.; Lample, G.; Saulnier, L.; et al. Mistral 7B, 2023, [arXiv:cs.CL/2310.06825]. 645
- 646
38. Abdin, M.; Aneja, J.; Awadalla, H.; Awadallah, A.; Awan, A.A.; Bach, N.; Bahree, A.; Bakhtiari, A.; Bao, J.; Behl, H.; et al. Phi-3 Technical Report: A Highly Capable Language Model Locally on Your Phone, 2024, [arXiv:cs.CL/2404.14219]. 647
- 648
39. Abdin, M.; Aneja, J.; Behl, H.; Bubeck, S.; Eldan, R.; Gunasekar, S.; Harrison, M.; Hewett, R.J.; Javaheripi, M.; Kauffmann, P.; et al. Phi-4 Technical Report, 2024, [arXiv:cs.CL/2412.08905]. 649
- 650
40. Brown, T.B.; Mann, B.; Ryder, N.; Subbiah, M.; Kaplan, J.; Dhariwal, P.; Neelakantan, A.; Shyam, P.; Sastry, G.; Askell, A.; et al. Language Models are Few-Shot Learners, 2020, [arXiv:cs.CL/2005.14165]. 651
- 652
41. OpenAI; Achiam, J.; Adler, S.; Agarwal, S.; Ahmad, L.; Akkaya, I.; Aleman, F.L.; Almeida, D.; Altenschmidt, J.; Altman, S.; et al. GPT-4 Technical Report, 2024, [arXiv:cs.CL/2303.08774]. 653
- 654
42. Anthropic. Claude - Models overview, 2025. Accessed: 2025-09-24. 655
43. Hernández-Cano, A.; Hägele, A.; Huang, A.H.; Romanou, A.; Solergibert, A.J.; Pasztor, B.; Messmer, B.; Garbaya, D.; Ďurech, E.F.; Hakimi, I.; et al. Apertus: Democratizing Open and Compliant LLMs for Global Language Environments. <https://arxiv.org/abs/2509.14233>, 2025. 656
- 657
- 658
44. DeepSeek-AI; Guo, D.; Yang, D.; Zhang, H.; Song, J.; Zhang, R.; Xu, R.; Zhu, Q.; Ma, S.; Wang, P.; et al. DeepSeek-R1: Incentivizing Reasoning Capability in LLMs via Reinforcement Learning, 2025, [arXiv:cs.CL/2501.12948]. 659
- 660
45. Team, Q. Qwen3 Technical Report, 2025, [arXiv:cs.CL/2505.09388]. 661
46. OpenAI. GPT-OSS: Open Source GPT Models, 2025. Accessed: 2025-09-23. 662
47. OpenAI. GPT-5 Models, 2025. Accessed: 2025-09-24. 663
48. Mistral-AI; Rastogi, A.; Jiang, A.Q.; Lo, A.; Berrada, G.; Lample, G.; Rute, J.; Barmentlo, J.; Yadav, K.; et al. Magistral, 2025, [arXiv:cs.CL/2506.10910]. 664
- 665
49. Luo, R.; Sun, L.; Xia, Y.; Qin, T.; Zhang, S.; Poon, H.; Liu, T.Y. BioGPT: generative pre-trained transformer for biomedical text generation and mining. *Briefings in Bioinformatics* 2022, 23, [https://academic.oup.com/bib/article-pdf/23/6/bbac409/47144271/bbac409.pdf]. bbac409, <https://doi.org/10.1093/bib/bbac409>. 666
- 667
- 668
50. Touvron, H.; Martin, L.; Stone, K.; Albert, P.; Almahairi, A.; Babaei, Y.; Bashlykov, N.; Batra, S.; Bhargava, P.; Bhosale, S.; et al. Llama 2: Open Foundation and Fine-Tuned Chat Models, 2023, [arXiv:cs.CL/2307.09288]. 669
- 670
51. Ankit Pal, M.S. OpenBioLLMs: Advancing Open-Source Large Language Models for Healthcare and Life Sciences. <https://huggingface.co/aaditya/OpenBioLLM-Llama3-70B>, 2024. 671
- 672
52. Labrak, Y.; Bazoge, A.; Morin, E.; Gourraud, P.A.; Rouvier, M.; Dufour, R. BioMistral: A Collection of Open-Source Pretrained Large Language Models for Medical Domains, 2024, [arXiv:cs.CL/2402.10373]. 673
- 674
53. Li, S.; Huang, J.; Zhuang, J.; Shi, Y.; Cai, X.; Xu, M.; Wang, X.; Zhang, L.; Ke, G.; Cai, H. SciLitLLM: How to Adapt LLMs for Scientific Literature Understanding, 2024, [arXiv:cs.LG/2408.15545]. 675
- 676
54. Lin, C.Y. ROUGE: A Package for Automatic Evaluation of Summaries. In Proceedings of the Text Summarization Branches Out, Barcelona, Spain, 2004; pp. 74–81. 677
- 678
55. Papineni, K.; Roukos, S.; Ward, T.; Zhu, W.J. Bleu: a Method for Automatic Evaluation of Machine Translation. In Proceedings of the Proceedings of the 40th Annual Meeting of the Association for Computational Linguistics; Isabelle, P.; Charniak, E.; Lin, D., Eds., Philadelphia, Pennsylvania, USA, 2002; pp. 311–318. <https://doi.org/10.3115/1073083.1073135>. 679
- 680
- 681
56. Banerjee, S.; Lavie, A. METEOR: An Automatic Metric for MT Evaluation with Improved Correlation with Human Judgments. In Proceedings of the Proceedings of the ACL Workshop on Intrinsic and Extrinsic Evaluation Measures for Machine Translation and/or Summarization; Goldstein, J.; Lavie, A.; Lin, C.Y.; Voss, C., Eds., Ann Arbor, Michigan, 2005; pp. 65–72. 682
- 683
- 684
57. Liu, Y.; Ott, M.; Goyal, N.; Du, J.; Joshi, M.; Chen, D.; Levy, O.; Lewis, M.; Zettlemoyer, L.; Stoyanov, V. RoBERTa: A Robustly Optimized BERT Pretraining Approach, 2019, [arXiv:cs.CL/1907.11692]. 685
- 686
58. He, P.; Liu, X.; Gao, J.; Chen, W. DeBERTa: Decoding-enhanced BERT with Disentangled Attention, 2021, [arXiv:cs.CL/2006.03654]. 687
59. Song, K.; Tan, X.; Qin, T.; Lu, J.; Liu, T.Y. MPNet: Masked and Permuted Pre-training for Language Understanding, 2020, [arXiv:cs.CL/2004.09297]. 688
- 689

60. Zha, Y.; Yang, Y.; Li, R.; Hu, Z. AlignScore: Evaluating Factual Consistency with a Unified Alignment Function, 2023, [arXiv:cs.CL/2305.16739]. 690
61. McKinney, W. Data Structures for Statistical Computing in Python. In Proceedings of the Proceedings of the 9th Python in Science Conference; van der Walt, S.; Millman, J., Eds., 2010, pp. 51–56. 692
62. Pedregosa, F.; Varoquaux, G.; Gramfort, A.; Michel, V.; Thirion, B.; Grisel, O.; Blondel, M.; Prettenhofer, P.; Weiss, R.; Dubourg, V.; et al. Scikit-learn: Machine Learning in Python. *Journal of Machine Learning Research* **2011**, *12*, 2825–2830. 694
63. Hagberg, A.; Swart, P.; S Chult, D. Exploring network structure, dynamics, and function using NetworkX. Technical report, Los Alamos National Lab.(LANL), Los Alamos, NM (United States), 2008. 696
64. Brin, S.; Page, L. The anatomy of a large-scale hypertextual Web search engine. *Computer Networks and ISDN Systems* **1998**, *30*, 107–117. Proceedings of the Seventh International World Wide Web Conference, [https://doi.org/https://doi.org/10.1016/S0169-7552\(98\)00110-X](https://doi.org/https://doi.org/10.1016/S0169-7552(98)00110-X). 698
65. Bird, S.; Klein, E.; Loper, E. *Natural language processing with Python: analyzing text with the natural language toolkit;* " O'Reilly Media, Inc.", 2009. 700
66. Zhang, T.; Kishore, V.; Wu, F.; Weinberger, K.Q.; Artzi, Y. BERTScore: Evaluating Text Generation with BERT, 2020, [arXiv:cs.CL/1904.09675]. 703
67. Reimers, N.; Gurevych, I. Sentence-BERT: Sentence Embeddings using Siamese BERT-Networks, 2019, [arXiv:cs.CL/1908.10084]. 705
68. Wolf, T.; Debut, L.; Sanh, V.; Chaumond, J.; Delangue, C.; Moi, A.; Cistac, P.; Rault, T.; Louf, R.; Funtowicz, M.; et al. Transformers: State-of-the-Art Natural Language Processing. In Proceedings of the Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing: System Demonstrations, Online, 2020; pp. 38–45. 707
69. Gunasekar, S.; Zhang, Y.; Aneja, J.; Mendes, C.C.T.; Giorno, A.D.; Gopi, S.; Javaheripi, M.; Kauffmann, P.; de Rosa, G.; Saarikivi, O.; et al. Textbooks Are All You Need, 2023, [arXiv:cs.CL/2306.11644]. 709
70. Zhou, L.; Schellaert, W.; Plumed, F.; Moros-Daval, Y.; Ferri, C.; Hernández-Orallo, J. Larger and more instructable language models become less reliable. *Nature* **2024**, *634*, 61–68. <https://doi.org/10.1038/s41586-024-07930-y>. 711
71. Dorfner, F.J.; Dada, A.; Busch, F.; Makowski, M.R.; Han, T.; Truhn, D.; Kleesiek, J.; Sushil, M.; Lammert, J.; Adams, L.C.; et al. Biomedical Large Languages Models Seem not to be Superior to Generalist Models on Unseen Medical Data, 2024, [arXiv:cs.CL/2408.13833]. 713
72. Zhai, Y.; Tong, S.; Li, X.; Cai, M.; Qu, Q.; Lee, Y.J.; Ma, Y. Investigating the Catastrophic Forgetting in Multimodal Large Language Models, 2023, [arXiv:cs.CL/2309.10313]. 716
73. Jin, K.; Wang, Y.; Santos, L.; Fang, T.; Yang, X.; Im, S.K.; Oliveira, H.G. Reasoning or Not? A Comprehensive Evaluation of Reasoning LLMs for Dialogue Summarization, 2025, [arXiv:cs.CL/2507.02145]. 718

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